BIOLOGICAL BOARD OF CANADA
UNDER THE CONTROL OF
THE MINISTER OF MARINE AND FISHERIES

BULLETIN No. XI

FUNDAMENTAL PRINCIPLES
OF
CHEMISTRY AND PHYSICS

BY
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Chemist, Fisheries Experimental Station (Atlantic)
Halifax, N.S.

OTTAWA
F. A. ACLAND
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INTRODUCTION

This pamphlet has been written as the result of suggestions made by some of the Fishery Inspectors attending the school given at the Atlantic Experimental Station for Fisheries during the winter of 1927. Lectures were given to these Inspectors in Chemistry and Physics, and they wished to have some of the facts of these two sciences available in a handy form.

No attempt has been made to write a text book, and anybody desiring further or more detailed information is referred to any of the readily available works on either Chemistry or Physics. No mathematical treatment of any kind has been given as it was felt that it was unnecessary for this work.

Many thanks are due to Dr. A. G. Huntsman, Dr. A. H. Leim, and other members of the staff of the Atlantic Experimental Station for Fisheries; and to Dr. Douglas McIntosh and Dr. J. H. L. Johnstone, of Dalhousie University, for their kind assistance.

H. RITCHIE CHIPMAN.

HALIFAX, N.S.,
July 5, 1927.

THE CONSTITUTION OF MATTER

Introduction: In considering the applications of the principles of Chemistry and Physics it is well to begin with some ideas as to the constitution of matter. This is a subject which has occupied the attention of scientists for many years, beginning several centuries before Christ and continuing to the present day. The speculations of the ancients are of great interest, and while at first glance some of their ideas may appear weird and fanciful, modern investigation has shown that some of the theories of the old philosophers are nct far removed from the trend of present day thought.

Among the various theories which have been suggested to account of the behaviour of matter, the Molecular Hypothesis has gained the most ground, and the more recent discoveries seem to show that it is a correct idea as to the way in which matter is built up from its component parts.

Kinetic Molecular Hypothesis: According to this hypothesis all matter is composed of extremely small particles which are in constant motion, their speeds varying with the temperature. These small particles are known as *molecules*, and matter of all kinds is built up of a very large number of them. The molecules are in turn built up of still smaller particles called *atoms*.

The Size of Molecules: The molecules of substances are extremely small and it is of course impossible to see them. The size of a molecule will depend upon what kind of molecule it is, but the average diameter may be taken as about forty millionths of an inch. It is very difficult for one's mind to imagine such a small object. If molecules of average diameter could be placed in a row touching each other, it would take 40,000,000 of them to make an inch. It must be remembered that the molecules are moving around and are colliding with their neighbours on all sides, and that while they are not all travelling at the same speed, their average speed varies as the temperature.

Combination of Atoms: It has been mentioned that molecules are built up of atoms. If the molecules of a substance are composed of atoms of the same kind, the substance is known as an *element*. The elements will be discussed in a later section. If however, the substance is composed of molecules which are built up of atoms of different kinds, it is known as a *compound*. When

two substances combine to form a compound, their molecules break up into atoms which join together so as to form the molecules of the compound. The atoms which combine to form a compound always unite in the same proportions, or in simple multiples of those proportions. In the case of sodium chloride, which is a compound, the sodium atoms and chlorine atoms are united together in fixed proportions: no matter where the sodium chloride is obtained, it will always have the same proportion of sodium and chlorine. If we consider the combination of copper and oxygen we find that there are two oxides of copper, cuprous oxide and cupric oxide. In cupric oxide there is twice as much oxygen as in cuprous oxide.

COMPOUNDS AND MIXTURES: A compound must not be confused with a mixture. In a compound, the separate parts cannot be separated unless the original compound be broken up and a new substance formed. In a mixture the parts can be separated by mechanical means. If we take some finely powdered iron and powdered sulphur and mix them we get a grey powder. If we examine this by means of a microscope we can see the particles of iron and sulphur side by side and the iron may be attracted by a magnet. If we place this powder in some carbon bisulphide, the sulphur will be dissolved and the iron will remain. We can thus easily separate the component parts and we are dealing with a mixture. In a mixture the proportions of the components are not fixed and bear no relation to each other. In the case of the iron and the sulphur we can take any amount of each that we please.

Now let us take some of this mixture of iron and sulphur and heat it in a flame. It immediately commences to glow and solidifies into a hard greyish mass which does not look anything like iron or sulphur. If we powder this mass and examine it we find that all the particles look alike and we cannot distinguish the iron from the sulphur: we also find that carbon bisulphide does not remove the sulphur as it did formerly. We find it to be completely different from either the iron or the sulphur. If we analyse this substance we find that the iron and sulphur exist in proportions that bear a definite relation to each other. We are now dealing with a compound.

We shall now consider the fundamental ideas concerning heat and its uses.

HEAT

DEFINITION OF HEAT: Heat is not matter but is a form of energy. The molecules possess energy, known as *kinetic energy*, which keeps them in constant motion, and this energy is due to the heat which they possess. When the molecules of a body gain

or lose heat they gain or lose kinetic energy. When they gain heat their temperature will rise, and when they lose heat their temperature will fall. It is important to understand that heat is not matter but is a form of energy, and the heat which is possessed by the molecules of matter is the kinetic energy which keeps them in motion.

Heat and Temperature: Heat is not to be confused with temperature as they are two different things. Heat is a form of energy. Temperature is a condition of matter which determines the flow of heat from one body to another. A very good analogy which makes this more easy to understand is to consider water flowing from a high level to a low level. The *amount* of water which flows is analagous to heat which is the quantity of energy. The *pressure* of the water depends upon the difference in height between the high and low levels. This is analagous to temperature which merely determines the direction of the flow of heat and the rate at which it will flow. Temperature is what determines the flow of heat, and heat will always flow from a body at a higher temperature to one at a lower temperature.

We get certain energy from water, but we can only get it when the water can flow from one level to another. In a similar way we can only use heat energy when it can flow from one temperature to another. Also, just as water cannot go uphill unless it is forced, we cannot get heat to go from a low temperature to a higher temperature unless we do it by mechanical means. To heat a body, we place it in contact with a body at a higher temperature and the heat will flow into it. When it comes to cooling a body we have to place it in contact with an object which is at a lower temperature.

As heat, like water, cannot flow of its own accord uphill, we cannot use the vast amount of heat that is in bodies around us unless those bodies are at a temperature higher than their surroundings. The ocean is a vast body of water and contains a very great amount of heat. But this heat can never be utilized unless we can provide a region of lower temperature so that the heat may flow. It would require too much energy to create the region of lower temperature to make it worth while using this source of heat.

The Measurement of Heat: The quantity or amount of heat is measured by its effects. The units commonly used are the *calorie* and *the British Thermal Unit* (B.T.U.). The calorie is the amount of heat necessary to raise the temperature of one gram of water one degree on the Centigrade scale. The British Thermal Unit is the amount of heat necessary to raise the temperature of one pound of water one degree on the Fahrenheit scale.

The calorie is a very small unit and often it is more convenient to use what is known as the *Large Calorie.* This is sometimes called the *Calorie* (spelled with a capital letter), and is the amount of heat necessary to raise one kilogram (one thousand grams) of water one degree Centigrade. It is to be pointed out that the definitions of the Thermal units specify unit weight of water in every case.

CONDUCTION: Heat travels from one place to another in three ways, by conduction, convection, and by radiation. If we place one end of a bar of iron in a fire and hold the other end in the hand, we soon feel the end which we are holding getting hot. In this case the heat is conducted along the bar from molecule to molecule.

CONVECTION: If we heat a pot of water the lower layers of water get hot and rise through the rest of the water. Owing to this gradual mixing the whole body of the liquid gets hot. If the water is heated in a glass vessel we can see the currents of warm water moving upwards. In this way of transmitting heat there is an actual movement of the particles of matter in what are known as convection currents. This takes place in liquids and gases. We all know that heated air ascends and we can see the convection currents of heated air rising from a radiator or stove.

RADIATION: When heat is transmitted by radiation, there is no movement of matter, and, indeed, there need be no matter present at all. Heat is radiated by the sun and it passes through space reaching the earth. As soon as the radiated energy meets any matter, that piece of matter will absorb the energy and become hot. In this case the heat is not conducted by anything nor is there a convection current to bring it. All bodies radiate heat in an amount proportional to their temperature and their nature. This energy is transmitted through space like light: whenever a body is exposed to it, that body will absorb it and the temperature of the body will rise.

These methods by which heat will travel from one place to another are of great importance in heating and cooling. In the case of the thermos bottle all three are considered. The liquid is placed in a glass bottle because glass is a poor conductor of heat; this bottle is surrounded by a space from which the air has been removed to prevent convection currents; and finally the surface of the glass vessel is silvered because polished surfaces will neither radiate or absorb heat as much as a rough surface. In refrigeration the air is kept in motion to allow convection currents to carry heat away from the bodies being cooled. The effects of radiation are not very large in the case of refrigeration and not much attention has to be paid to that method of heat transfer.

THE MEASUREMENT OF TEMPERATURES: Temperature is usually measured by a mercury thermometer. Most bodies expand when heated, and the expansion is approximately proportional to the increase in temperature. A thermometer consists of a long tube of narrow bore with a small bulb on one end, the other end being sealed. A scale is placed on the tube and the bulb contains mercury. (See Fig. 1.) For thermometers it is convenient to use a liquid which is placed in a bulb. When heated the liquid rises into the stem of the thermometer, and the length of the column, which serves as a measure of the temperature of the bulb, is read from a scale. For several reasons mercury is the most convenient liquid. Mercury boils at 357°C. or 647°F., and freezes at −39°C. or −38° F., so that it may be used to measure temperatures lying between these points. For measuring temperatures below −39°C. alcohol, which freezes at −114°C. or −173°F., may be used.

Temperature is purely a relative measurement and depends upon the choice of various points whose temperature is fixed. The freezing-point of a liquid is such a point, as when a liquid is frozen the temperature will remain constant from the time the solid appears until all of the liquid is converted into solid. The freezing point and the boiling point of pure water are the points which are used as a basis for most temperature measurements. When pure water is mixed with ice and the mixture well stirred the temperature will become constant at what is known as the *freezing-point*, and will remain constant as long as the ice and water are together and in contact with one another. This may conveniently be taken as a low temperature point from which to measure temperature. Another similar point is the *boiling-point*. When water is heated until it boils, the temperature remains constant at the point at which the water commenced to boil until all the water has been turned into steam. The boiling point of a liquid is altered by changes in the atmospheric pressure, and when the pressure is not stated, it is supposed to be 76 centimeters of mercury.

CALIBRATION OF THERMOMETER: To calibrate a thermometer it is placed in a mixture of pure ice and pure water and the point where the mercury rests is noted. This marks the freezing point. The thermometer is then placed in the steam of water boiling under a pressure of 76 centimeters of mercury and the boiling point is noted. Having these points the distance between them can be divided into as many parts as may be desired.

THE FAHRENHEIT SCALE: On the Fahrenheit scale the freezing point of water is marked 32 and the boiling point taken as 212. The space between them is divided into 180 equal parts, each one denoting one degree. The scale is continued below 32, and 0

denotes the temperature which Fahrenheit originally reached using ice and salt. He believed that this was the lowest temperature obtainable and hence marked it as zero.

THE CENTIGRADE SCALE: On the Centigrade scale, which is generally used in all scientific work, and in most European countries, the freezing point of pure water is taken as 0 and the boiling point as 100. The space between is therefore divided into 100 parts, each one denoting one degree.

The difference between the scales of the two systems is shown graphically in Fig. 1. To convert Centigrade readings into Fahrenheit, multiply by nine-fifths and add thirty-two. To convert Fahrenheit readings into Centigrade subtract thirty-two and multiply by five-ninths.

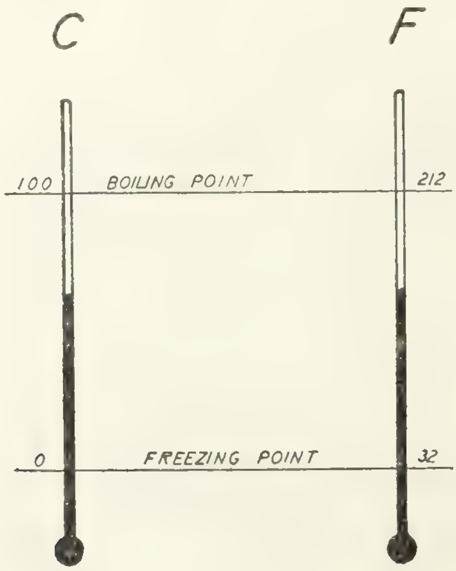


FIG. 1

THE ABSOLUTE SCALE: If heat is applied to molecules they take up the increase in energy and their speed will increase. Suppose we remove all of their heat: they would then possess no motion at all. Such a condition has never been realized, but the temperature at which that would occur is calculated to be about 273 degrees below zero on the Centigrade scale and about 460 degrees below zero on the Fahrenheit scale. This temperature is known as *Absolute Zero*, and the temperatures measured on a scale which has absolute zero as its zero and 273° the same as the

Centigrade zero are known as *absolute temperatures*. Now every body existing at room temperature has had heat given to it to raise its temperature from the absolute zero to its present temperature. If the body is a large one it will contain a large amount of heat although its temperature may not be very high. A very large block of ice may contain much more heat than a few drops of boiling water.

Specific Heat: The *specific heat* of a body is the amount of heat necessary to raise the temperature of unit weight of it one degree. Specific heat is of great importance in heat problems. The smaller the specific heat of a body the less heat will be required to raise it to the desired temperature. The amount of heat used to raise the temperature of a body a certain number of degrees is obtained by multiplying the change in temperatures by the specific heat of the body and by its weight.

Latent Heat: When water is heated over a flame the temperature will gradually rise. Finally the water will boil and it will be observed that the temperature remains constant until all of the water has been converted into steam. While the temperature has been constant, heat has been constantly going into the body, but why has that not resulted in a change of temperature? It has been mentioned that the molecules have an attraction for one another, and in a liquid they are close enough to come within the range of each other's attractions. It will require the use of a certain amount of energy to cause the molecules to separate, and that is why the heat is used up while the temperature remains constant. This heat which is required to convert the water at boiling temperature into steam at the same temperature is known as *latent heat*. When steam condenses this heat is given off as the water is formed. When ice is melting the temperature will remain constant until all of the ice is melted. The heat that is absorbed by the ice during this period becomes latent heat. Thus we see that whenever a solid turns into a liquid or a liquid turns into a gas, heat is required to make the change. This heat is absorbed by the body in question. Conversely, whenever a gas is converted into a liquid or a liquid into a solid, heat is given off by the body.

The latent heat of melting of ice is made use of in cooling by means of ice. When ice is melted it will absorb the heat from its surroundings. If fish are placed on ice, as the ice melts it will absorb heat from the fish and their temperature will gradually fall, the temperature of the melting ice remaining the same.

GASES

Behaviour of Molecules: In a gas most of the molecules are quite far apart in proportion to their size, and they are travel-

ling in all directions with a speed proportional to the temperature of the gas. It is easier to get a good mental picture of the molecules in a gas if one thinks of them as small elastic balls which are moving around in all directions. When they hit the walls of the vessel or hit one another they will bounce off in another direction. While the molecules will bounce off each other in the course of their travel, if they are brought very close together they will have an attraction for each other and pack together. This is of great importance in the liquefaction of gases and will be mentioned later.

Now it is well known that a gas will completely fill any vessel which contains it, and has no surface like a liquid. When you consider the vessel as being filled with a large number of molecules rushing about it is easy to see why gases fill all available space. This also explains the rapidity with which odours will penetrate to all corners of a large room, and why smoke will soon be detected at a considerable distance from a fire.

PRESSURE, VOLUME, AND TEMPERATURE: The actions of gases are governed by three variable conditions which must always be taken into account. They are, pressure, volume, and temperature. A definite relation has been found to exist between them and may be stated as follows: The volume of a gas is directly proportional to the absolute temperature and inversely proportional to the pressure. This may be better understood by a reference to Fig. 2A. The cylinder "C" is fitted with a tight piston

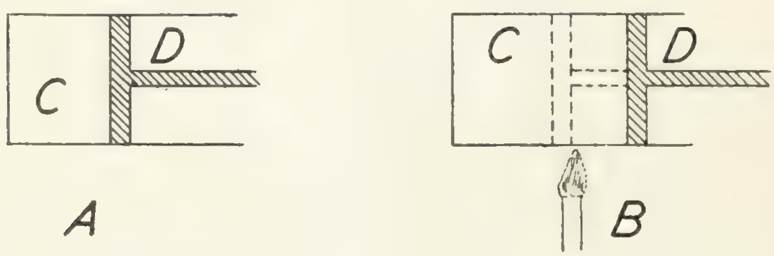


FIG. 2

"D" and contains a quantity of gas. The piston is free to move in and out of the cylinder. The gas in the cylinder occupies a definite volume. Now let us increase the temperature of the gas by heating it. Immediately the gas will expand, the volume will grow greater and the piston will move out as shown in Fig. 2B. If on the other hand the gas be cooled it will contract and the piston will move in. This shows that the volume of a gas varies directly with the

temperature. Now suppose we exert a pressure upon the gas by forcing in the piston. The gas will be compressed and the volume will become smaller. If we release the pressure upon the gas by drawing out the piston, the gas will expand and its volume will become greater. Thus the volume varies inversely as the pressure. When the pressure increases the volume becomes smaller, and when the pressure decreases the volume becomes greater.

Let us see if we can understand this relation between volume, pressure and temperature by considering what happens to the molecules. Let us imagine the cylinder of Fig. 2 to contain molecules moving about in all directions. As they travel about they will bounce off from the walls and the piston. As there are a very large number of molecules there will be a great many hits on the walls. On account of the very large number we may consider that there are the same number of hits on all walls at any second. This striking of the molecules against the walls of the vessel is the pressure, and we know that the pressure of a gas is the same in all directions. Now let us increase the temperature. This will increase the speed of the molecules and there will be a much greater number of hits per second than before. This will thus increase the pressure of the gas. If it is possible for the volume to change, that is if one of the walls is movable, this increase in pressure will cause the gas to expand. In the case of the cylinder of Fig. 2 the piston will move out as a result of the increased pressure and the volume will increase. By seeing what happens to the molecules themselves a good picture of the relation between volume, pressure, and temperature can be obtained.

The Atmospheric Pressure: The atmosphere which surrounds us produces a pressure on account of its molecules striking objects which are exposed to its force. Unless there is a wind, which increases the speed of the molecules which are travelling in a certain direction, we are never conscious of the atmospheric pressure as we feel it equally on all sides. The pressure of the air is however quite considerable and is approximately 14.7 lbs. per square inch. If we have some gas in the cylinder of Fig. 2 we must remember that the air is pressing on the outside of the piston. We have, therefore, a force acting on both sides of the piston; that due to the air pressure tending to move it into the cylinder; and that due to the gas pressure tending to move it out of the cylinder. If we increase the pressure of the gas until it is greater than the air pressure the piston will move outwards, while if we decrease the gas pressure the air pressure will drive in the piston until the pressure of the gas inside becomes again equal to that of the air outside.

The Barometer: The atmospheric pressure is measured by means of a barometer. A simple barometer is shown in Fig. 3. It consists of a glass tube about a yard long which dips into a small vessel containing mercury. The upper end of the tube is sealed. Before the tube is placed in the vessel it is completely filled with mercury, the open end being uppermost. As soon as the tube is inverted we would expect the mercury to fall out, but we must remember that the air is exerting a pressure upon the mercury surface at "A." The mercury will fall in the tube until the mercury column is of the weight that will be supported by the pressure of the air at "A." This then is a means of measuring the atmo-

FIG. 3

spheric pressure. If the air pressure increases it will exert more pressure on the mercury surface "A." This will drive some more of the mercury up the tube and the upper level "B" will rise. If the air pressure decreases it will exert less pressure at "A" and the upper level "B" will fall. A scale placed beside the tube allows the upper level "B" to be measured. The measure is the number of inches or centimeters between the lower level "A" and the upper level "B."

The average height of a mercury column which the air will support is about 30 inches or about 76 centimeters. This height

will of course vary with the weather conditions. At the top of high mountains where the pressure is much less, the height of the mercury column will be decreased.

The height of a column of liquid which the air will support depends upon the weight of the liquid. If a barometer were constructed using water instead of mercury the tube would have to be about thirty-four feet high as the air will support a column of water about thirty-two feet in height. It will not support a longer column and that is the reason why ordinary suction pumps will not raise water to a greater height than about thirty-two feet.

Aneroid Barometer: In the aneroid barometer, which is commonly used as a portable instrument, the long mercury column is dispensed with. In its place there is a collapsible metal box which is compressed by the atmospheric pressure. As the pressure increases the box collapses further, the movement being shown by a needle moving on a scale. This type of instrument is much used as a portable barometer in places where a long mercury column would be in the way.

LIQUIDS

Behaviour of Molecules: Matter in the form known as a liquid is similar to a gas in that it consists of a large number of molecules which are moving about with a speed proportional to their temperature. The difference between a gas and a liquid is that the molecules of the liquid are much closer together, and in fact are so close together that there exists an attractive force between them. It is the presence of this attractive force that accounts for the formation of a surface and other properties peculiar to liquids.

Solutions: One of the most important properties of a liquid is that of being able to dissolve certain solid bodies. Various solid bodies will completely dissolve in certain liquids and the resulting liquid is known as a *solution*. The liquid which dissolves the solid is called the *solvent*. While the more common solutions are those where water is the solvent, other liquids will dissolve certain substances. As an example of this we can consider the dissolving of fats by gasoline.

There are other classes of solutions, but what we consider chiefly is that of solids in liquids. We also have liquids in liquids as alcohol and water; gases in liquids as soda water; and other examples.

Suspensions: If we mix clay and water together we get a cloudy liquid, which will become clear when the small particles of sand settle. Here we are not dealing with a solution but a *suspension*.

There are many cases where a solid may be suspended in a liquid in such small particles that it will even go through a filter, but it will not be considered as being dissolved. In a true solution, the particles of the dissolved substances are present as molecules distributed among the molecules of the solvent, and cannot be separated by any form of filter.

DIFFUSION: If we introduce a small quantity of a strongly smelling gas into a room, the odour will soon penetrate into all parts. This is due to the diffusion of gases. In a similar fashion liquids will diffuse into one another. If we carefully add a small quantity of a strong solution of copper sulphate to some water the blue colour of the copper sulphate solution will slowly spread throughout the water. If the glass be allowed to stand the liquid will assume an even blue colour due to the diffusion of the copper sulphate throughout the water.

If a small crystal of salt be placed in a glass of pure water some of the molecules of the salt will separate from their neighbours and move off among the molecules of water. This is shown graphically in Fig. 4A. The molecules of the salt are represented

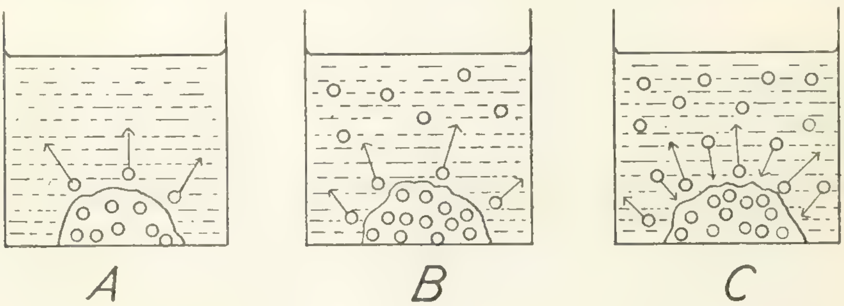


FIG. 4

on a vastly magnified scale as leaving the crystal. As shown in Fig. 4B they will move among the molecules of the water. To prevent confusion the molecules of water are not represented. As they travel around in the water some of them will come back to the crystal of salt. At the same time a further supply will be leaving the crystal and entering the water. This is shown by Fig. 4C where the direction of travel is shown by the small arrows. Finally a point will be reached where the number leaving the crystal will be equal to the number returning. The process of solution will reach a point of equilibrium and no more salt will dissolve. Of course it is to be understood that the molecules do not stop their motion but as there is the same number leaving as returning there is the same quantity of salt left undissolved.

SATURATION: A solvent will only hold a certain amount of a solid in solution. This amount will vary with the temperature and of course with the solid and the solvent. In general the higher the temperature the more the solid will dissolve. In the case of gases, however, the higher the temperature the less the gas will dissolve.

Returning to the consideration of the piece of salt shown in Fig. 4 we see that only a certain number of salt molecules can remain in the solvent. If any more come off from the salt, some will return to the salt from the water, so that the amount present as dissolved in the water will remain the same. If there is sufficient water present to hold all of the molecules of the salt, the piece of salt will completely disappear. If, on the other hand there is not sufficient water present some of the salt will remain undissolved.

It is important to remember the fact that a solvent will hold a definite amount of dissolved substance at a certain temperature. When a solution contains the maximum quantity of the dissolved substance that it can contain at the temperature at which it is, it is known as a *saturated solution*. If a further amount of the solid be added to a saturated solution it will not dissolve but will remain at the bottom of the glass. If the temperature now be raised the power of the solvent to hold more solid will be increased and more of it will dissolve. On the other hand if the temperature be lowered the ability of the solvent to hold the solid will decrease and some of it will deposit on the bottom of the vessel.

As long as there is some of the solid in contact with the solvent you are certain that you have a saturated solution. It is of course necessary that the solution be well stirred in order for all portions of the liquid to come into contact with the solid. In making a concentrated brine, as long as there is solid salt at the bottom of the vessel, you will have as strong a solution as you can ever expect for that temperature. If the brine is not stirred, and some pure water be added to the top of the solution, it takes some time for the diffusion of the liquids. The solution must be well stirred. When the solid is in contact with the solution and the temperature drops some of the solid will deposit from the solution. In any event the solution will remain saturated.

DENSITY AND SPECIFIC GRAVITY: One method of determining the extent of saturation of a solution, or the amount of solid that is dissolved in it, is to determine the density or the specific gravity. The density of a substance is the weight of a unit volume. It is usually expressed in the metric system as the weight in grams of one cubic centimeter, or, in the cases of gases, one litre. The specific gravity is the relative weight of any volume of the substance compared with the weight of the same volume of water. A cubic centimeter of water weighs one gram so the density of water

is unity. If a cubic centimeter of some other substance weighs two grams its density is two. Specific gravity is usually measured by the English system as the weight of a certain volume of the substance compared to the weight of that same volume of water.

THE HYDROMETER: The specific gravity of solutions is often determined by the hydrometer. The hydrometer which is shown in Fig. 5 consists of a tube weighted with mercury and having a

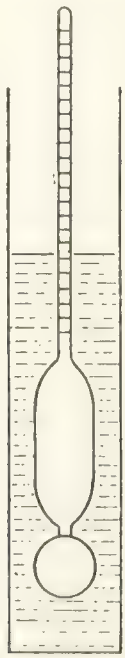


FIG. 5

long stem carrying a scale. This tube will sink in a liquid to a depth depending upon the specific gravity of the liquid, and the depth to which it sinks may be read from the scale. These instruments are manufactured with special scales for special solutions and in the case of these instruments the concentration of the liquid may be read directly from the scale. Salimeters are hydrometers specially made to read the concentration of salt solutions.

OSMOSIS: Among the properties of solutions, *Osmotic Pressure* is one of the greatest importance as many of the natural processes of animal and vegetable life depend upon it. Although the molecules of the dissolved substances are very small, the molecules of the solvent are often smaller, and there are certain membranes as

bladders and similar membranes which will allow the water to pass through but will retain the dissolved substance. Such membranes, known as semi-permeable membranes, are found extensively throughout the animal and vegetable worlds. For experimental use semi-permeable membranes are prepared artificially.

If we divide a vessel into two parts by means of a semi-permeable membrane, as shown in Fig. 6, and place a strong salt solution on one side and pure water on the other, it will be found that the level of the liquid on the side of the strong salt solution will gradually rise while that on the side of the pure water will fall. The difference in pressure that results is known as the *osmotic pressure*. The passage of a solvent through a semi-permeable

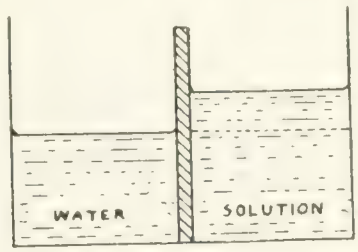


FIG 6

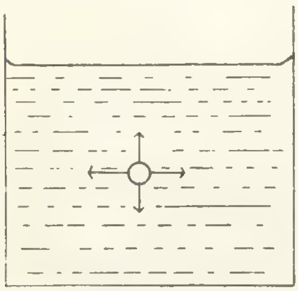
membrane is known as *osmosis*. The principle of osmosis is found extensively in nature and by it our body cells absorb substances from the blood, and our kidneys remove water. The walls of most living cells consist of semi-permeable membranes, or at least of membranes which are almost semi-permeable.

Thus we see that whenever we have a salt solution separated from the pure solvent by means of a semi-permeable membrane, there will be a passage of the pure solvent through the membrane. If instead of having pure solvent on one side we have a weaker solution of salt, the same process will occur and the solvent will pass through from the side of the weaker solution to that of the stronger. In osmosis the passage of water is always from the side of the weaker solution to that of the stronger.

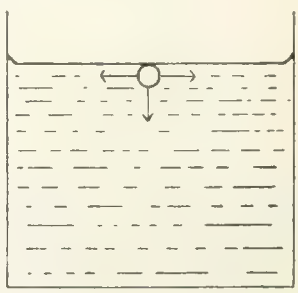
In the preceding discussion we have imagined a perfect semi-permeable membrane that will allow the molecules of the solvent to pass through but will prevent the passage of the molecules of the solute. It is however, impossible to find an ideal membrane, and they will allow some of the dissolved substance through. In the application of osmosis to the salting of fish this is of great importance.

THE SALTING OF FISH: In the salting of fish, dry salt is placed over the fish; the water is removed from the cells of the flesh and some of the salt enters. The removal of the water hinders the action of decay. On soaking the fish before cooking the process is reversed, the water is put back into the flesh and the salt is taken out. If the membrane which comprises the walls of the cells were ideally semi-permeable, no salt would enter at all. But this is not the case and not only will sodium chloride enter but also the various other salts which may be present. These impurities have certain actions on the flesh of the fish and considerably alter its flavour and condition. This is especially the case with salts of calcium and magnesium, which tend to produce a white and firm flesh which has an altered flavour.

SURFACE EFFECTS: All the molecules in a liquid are close enough together to make their attractive forces felt upon one another. If we consider a molecule in the centre of the liquid we see that it is attracted by its neighbours on all sides. This is shown in Fig. 7A, and shows that the forces of attraction are the



A



B

FIG 7

same in all directions. If, however, we consider a molecule on the surface of the liquid as shown in Fig. 7B we see that it is attracted by its neighbours on the level and below, but there are no molecules above it so there is no attractive force from that direction. The result of this is that the molecule is subjected to a downward force and the whole surface of the liquid acts as if it were an elastic skin. This results in certain effects common to all liquids. Owing to the attraction of the molecules on the surface by the sides of the containing vessel the surface of a liquid will tend to take the shape

shown in Fig. 8A. This is very marked in narrow tubes. If the liquid is one which does not wet the sides of the vessel, as for example mercury, the surface will take the shape shown in Fig. 8B. Liquids of this nature are however not very common.

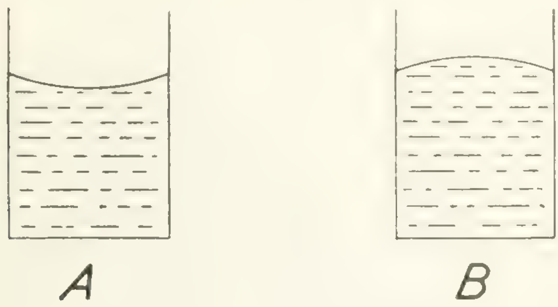


FIG. 8

Vapour Pressure: The speed of the molecules which is proportional to the absolute temperature of the liquid is the *average* speed and there will be several molecules with a speed greater than this. These will possess sufficient energy to escape from the attractions of their neighbours, leave the surface of the liquid, and escape into the air above. This process gradually goes on and the liquid is said to *evaporate*. This is shown in Fig. 9. If

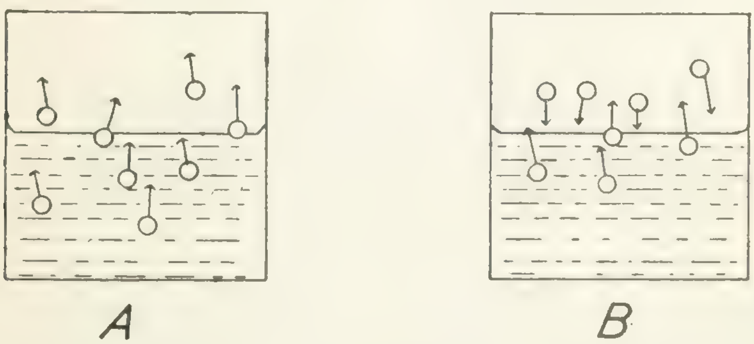


FIG. 9

the space above the liquid is enclosed the molecules which leave the liquid cannot escape and they will finally return to the liquid. Just as in the case of the solution of the salt, a point will be reached, shown in Fig. 9B, where there are as many leaving the surface as

returning, and a point of equilibrium will be reached. So a liquid will not evaporate into a closed space indefinitely. The molecules which are in the space above the liquid exert a pressure which is known as the *vapour pressure* of the liquid at that particular temperature. The vapour pressure is proportional to the temperature and increases as the temperature increases.

EVAPORATION: We see now that any liquid will gradually lose its faster-moving molecules, and that if these molecules are free to leave the space above the liquid, the liquid will evaporate. If the molecules are assisted to leave by passing a current of air over the surface, the evaporation will be much quicker. The temperature of the liquid is proportional to the speed of the molecules so that if the fast ones are removed the temperature of a liquid will be lowered. If we can cause a liquid to evaporate quickly we can cool it considerably. If air be blown through some ether placed in a glass upon a wet board as shown in Fig. 10, the evaporation of the ether cools it so much that it freezes the glass to the board.

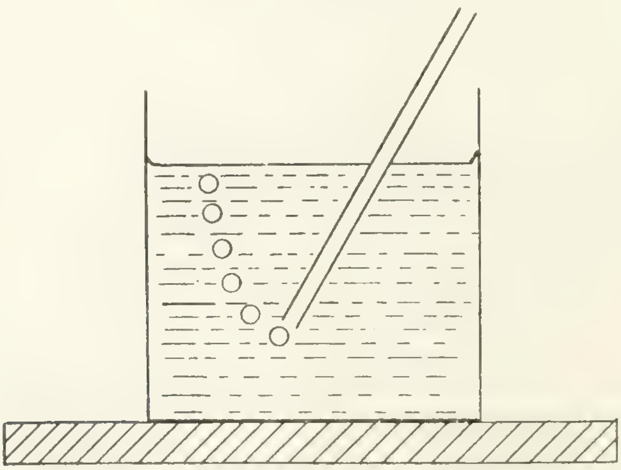


FIG. 10

Water may be cooled by this method if it is placed in porous earthenware pots, as is often done in tropical countries. The water slowly soaks through the porous pot and forms a thin film of water on the outside. This thin film quickly evaporates in the dry air and this rapid evaporation cools the pot.

BOILING: If we raise the temperature of a glass of water we speed up the molecules and thus increase the number that are able to escape from the liquid. This increases the vapour pressure.

If the vapour pressure of the liquid be increased until it is a very little greater than the pressure of the atmosphere, bubbles of vapour will form in the body of the liquid and rising to the top will escape. The liquid is then said to boil. Whenever the vapour pressure of a liquid is made a fraction greater than the pressure of the atmosphere the liquid will boil. The boiling point of a liquid will therefore depend upon its vapour pressure. Ether has a very high vapour pressure at ordinary temperatures so that it does not require much of a rise in temperature to make it boil. Strong salt solutions on the other hand have a lowered vapour pressure and therefore have a higher boiling point than pure water. The boiling point of a liquid will be governed by the pressure of the atmosphere. On the top of high mountains where the air pressure is lowered, it will not be necessary to heat the water as much to make it boil. If the mountain be high enough, it will be impossible to boil an egg as the water will boil at a temperature too low to cook the egg.

Condensation: Let us see what happens when we cool a vapour. As the temperature is lowered, the speed of the molecules becomes less and finally they are not moving fast enough to keep out of each other's attractions and they will group together forming drops of liquid. The process is just the reverse of evaporation and is governed by the same natural laws.

Suppose we consider a substance which exists as a gas at ordinary temperatures. We may lower the temperature until it falls considerably below room temperature and still the molecules may be moving too quickly to be attracted to each other. It will then be impossible to make this gas condense to a liquid. If, however, we increase the pressure as well as lower the temperature we cause the molecules to crowd together with the result thatwe can make them attract each other and the gas will then condense. This is the case with ammonia and some other gases. These gases may be liquefied by cooling them and at the same time applying pressure.

Liquefaction of Gases: There are some gases which will not condense even with this treatment, and further steps have to be taken to make them liquefy. The molecules have an attraction for each other so that when they are quite close together it takes heat to separate them. The molecules possess kinetic energy and the temperature is proportional to this energy. If the gas be highly compressed so that the molecules are very close together, and then allowed to expand, the molecules will lose some of their kinetic energy in escaping from each other's attraction. The loss of this portion of their kinetic energy will result in a lowering of the temperature of the gas. So if highly compressed gas be allowed to

expand suddenly through a very small opening, the gas will become cooler and if this be repeated several times it will finally liquefy. This is the principle which is applied to the liquefaction of air, oxygen, nitrogen, and other gases.

REFRIGERATION MACHINES: The principle of cooling by sudden expansion is made use of in certain refrigeration methods. A liquefied gas is allowed to expand suddenly with the result that it becomes much colder. If this expansion occurs in a series of pipes used in a cold storage plant, heat will be taken from the objects placed on or around the pipes. The gas is then compressed again until it is liquid, pumped back again, and the process repeated.

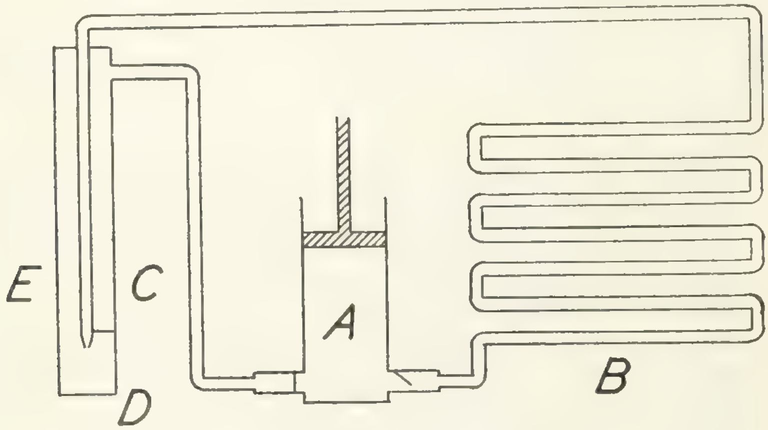


FIG. 11

A diagram of a machine for the liquefaction is given in Fig. 11. The gas is compressed by the compressor A and is pumped into the coils B which are surrounded by streams of cold water. The compression of the gas causes it to become heated, and this heat is carried away by the running water. The gas then passes into the tube C which ends in a small jet. The gas rushes through the jet and expands suddenly into the chamber D. The passage of the gas through the jet cools it and it then goes through the pipe E. This pipe surrounds pipe C and the gas which has expanded helps to further cool the gas passing through pipe C. Finally the gas returns to the compressor. This is kept up until finally the gas will get so cold that it will form drops of liquid as it enters the chamber D. The liquid may be withdrawn at D and suitable valves allow a fresh supply of gas to be taken into the system.

For refrigeration work the principle is the same only the chamber D is extended to form the series of cooling coils. Electric refrigerators of the domestic type, which are now widely advertised, work on this same principle and generally use sulphur dioxide as the gas which is liquefied. Ammonia is commonly used in commercial refrigeration plants.

THE FREEZING POINT: We have seen that the boiling point of a liquid can be explained by a consideration of its molecules. The same reasoning can be applied to a discussion of its freezing point. If we lower the temperature the speed of the molecules gets less and finally they are not travelling with sufficient speed to escape from each other's attractive forces. They will then form little groups, and, this group formation spreading throughout the liquid, the whole mass of liquid will become a solid. The temperature at which this occurs is known as the *freezing-point* of the liquid. While the boiling point of a liquid is dependent upon the pressure of the atmosphere, its freezing point is not appreciably affected by changes in the pressure. There is really a slight effect, but it is so small that it is generally neglected.

The addition of a dissolved substance to a liquid tends to *lower* its vapour pressure. The result of this is that it *lowers* the freezing point of the solution and *raises* the boiling point. This is well known and is clearly shown in the case of sea water which freezes at a lower temperature than pure water. Strong salt solutions boil at a higher temperature than pure water.

When a crystalline body containing water of hydration is dissolved in water heat is absorbed by the system. This results in a lowering of the temperature of the solution. When solid calcium chloride and ice or snow are mixed together the solution of the calcium chloride will cool the resulting mixture so that very low temperatures may be obtained.

DISSOCIATION: When acids, bases, and salts are dissolved in water they are dissociated into two components each bearing an electric charge. These component parts are known as *ions*, those bearing a positive electric charge are the *positive ions*, and those bearing a negative charge are the *negative ions*. The sum of all the electric charges on the ions is always zero so that a solution of an acid, base, or salt is electrically neutral.

Acids dissociate into *hydrogen ions* bearing a positive charge and negative ions bearing a negative charge. The nature of the negative ions depends upon the nature of the acid. Hydrochloric acid dissociates into hydrogen ions and chloride ions; sulphuric acid into hydrogen ions and sulphate ions; acetic acid into hydrogen ions and acetate ions, and so on. Acids do not completely dissociate and the strength of the acid depends upon the amount

of hydrogen ion that is present. Hydrochloric acid is a strong acid; acetic acid is a weaker acid; while carbonic acid is a very weak acid. All acids dissociate so as to give hydrogen ions all of which carry positive charges.

Bases dissociate into metallic ions carrying a positive charge and *hydroxyl ions* carrying a negative charge. The nature of the metallic ion depends upon the nature of the base. Ammonium hydroxide dissociates into ammonium ions with a positive charge and hydroxyl ions with a negative charge; sodium hydroxide into sodium ions with a positive charge and hydroxyl ions with a negative charge. As in the case of acids, the strength of the base depends upon the degree of dissociation and with the base, depends upon the concentration of the hydroxyl ion. Sodium hydroxide is a strong base while ammonium hydroxide is a weak base.

In the case of salts, there are metallic ions carrying a positive charge and acidic ions carrying a negative charge. Sodium chloride gives sodium ions and chloride ions; iron sulphate gives iron ions and sulphate ions, and so on. The degree of dissociation of salts varies with the nature of the salt, but in general salts dissociate to a greater degree than acids or bases.

Dissociation is an equilibrium as in the case of the solution of a solid. When a piece of salt is placed in water it dissociates so as to give some ions. For every positive ion set free there is a negative ion, and these tend to attract each other and form an uncharged molecule. So in a solution of a salt there are free ions and undissociated molecules, the degree of dissociation depending upon the proportion of ions to uncharged molecules.

Electrolysis: It has been just shown that in the solution in water of an acid, base or salt, ions bearing electric charges exist in the solution. Now if we place in that solution electrodes bearing an electric charge, the ions carrying an opposite charge are attracted to the electrode. These ions travel to the elctrode and there give up their charges. They then become molecules.

In the case of water itself, we have both hydrogen and hydroxyl ions present; the hydrogen ions carrying a positive charge and the hydroxyl ions carrying a negative charge. If we add a little acid (to carry the current as water is a non-conductor), and place two electrodes in the water, one electrode bearing a positive charge and the other bearing a negative charge; the positive ions will be attracted to the negative electrode, and the negative ions will travel to the positive electrode. The hydrogen ions carrying the positive charge will therefore go to the negative electrode, give up their charge, and form molecules of hydrogen. Similarly the hydroxyl ions will go to the positive electrode, give up their charge, unite with the water surrounding the electrode and form free

oxygen. So if we pass an electric current through water we get hydrogen set free from one terminal and oxygen set free from the other.

If we electrolyse a solution of a salt we get various substances set free, depending upon the salt used. Solutions of sodium chloride give sodium and chlorine. The sodium combines with the water and forms sodium hydroxide, while the chlorine is set free.

SOLIDS

Behaviour of Molecules: In solids the molecules are very much closer together than in gases or liquids. It is believed that the molecules have definite positions in the solid body and they do not travel about as they do in the case of gases and liquids. However, they possess kinetic energy and therefore have motion. While this motion cannot allow them to escape from their positions they will vibrate in their places, and some of the properties of solids are ascribed to this molecular vibration.

Crystals: Solid bodies are either crystalline or non-crystalline. Crystalline bodies are those which form definite and regular shapes known as crystals. When these bodies are deposited from solutions they form crystals. The study of crystals forms a science known as crystallography. There are seven classes of crystals and all may be placed in one of these classes. The geometrical shape of a crystal is always definite, and whenever that crystal is formed it will always have the same shape and the same angles though they may differ in size. Recent work with X-rays have shown that the molecules have definite positions in the crystal and form what is known as a *crystal lattice.* Non-crystalline bodies have no definite shape and may be obtained in any form. If crystals are broken they will tend to fracture along straight lines which are geometrically related to their particular shape; non-crystalline bodies will break in any manner and will show no definite forms.

Hydrates: Some crystals contain water which is chemically combined but may be set free by the action of heat. This water is known as *water of crystallization* or *water of hydration*, and crystals containing this water are known as hydrates. Hydrates will break up when heated and form a powder while giving off the water as steam. It will be remembered that some of the molecules of a liquid will escape from the main body of the liquid and will form a vapour pressure. In a similar manner the water of hydration exerts a vapour pressure.

If the vapour pressure of the crystal is less than that of the water vapour in the air, the crystal will take up water from the air

and become moist. Some crystals will take up so much water that they will actually dissolve in the water which they take up. Substances which take up water from the air are known as *deliquescent*. If the vapour pressure of the crystal is greater than that of the vapour pressure in the air, the crystal will lose its water of crystallization and turn to a powder. Such substances are known as *efflorescent*. Whether a crystal will give up water or take it up will depend upon whether the water vapour pressure in the air is less than or greater than the vapour pressure of the crystal.

THE CAKING OF SALT: Owing to the presence of deliquescent bodies which are present as impurities, salt will absorb water from the air and cake. Table salt has these impurities removed so that it will flow freely and will not cake.

THE ATMOSPHERE

COMPOSITION OF THE AIR: The air is a mixture of gases, about one-fifth of which is oxygen. The remaining four-fifths is almost all nitrogen but there are small quantities of other gases, as argon and some of the other rare gases. Varying amounts of carbon dioxide, hydrogen sulphide, sulphur dioxide, etc., are found, depending upon local conditions. Air over cities or places where there is a lot of smoke will contain more carbon dioxide and sulphur compounds than air over the country.

HUMIDITY: There is always water vapour in the air, the amount depending upon various conditions, especially the temperature. The amount of water vapour which the air will hold is dependent upon the temperature, and the higher the temperature the more it will hold. The water vapour in the air causes a pressure known as the water vapour pressure. The proportion of water vapour present in the air to the amount of water vapour which that same air might hold at the same temperature is known as the *relative humidity*. Air will seldom have as much water vapour as it can hold, but when it has a high humidity it is almost saturated with water vapour. The air then feels "close" and "muggy." Wet objects will dry very slowly in such air as there is considerable water vapour present and it will not easily take up more water. On the other hand, when the air is not holding its full amount of water vapour it will easily take up water and objects will dry out much more quickly.

Our skin perspires more easily in dry air and we feel cooler and more comfortable. Dry air is air from which most of the water vapour has been removed. For certain industrial operations it is necessary to remove most of the water vapour and this may be done by passing the air through sulphuric acid. The warm air

of the summer months will dry objects readily, as owing to its high temperature the air will hold a large quantity of water vapour. In winter, as the air is at a lower temperature it will not hold as much water vapour and it becomes saturated with water.

DEW: When the air is cooled its capacity for holding water vapour is lowered and finally the water vapour will condense and deposit in drops. If a cold object is placed in the air it will rapidly cool the layers of air that are immediately surrounding it. As still air is not a good conductor of heat, these layers will remain cool as heat will not flow into them from the neighbouring layers. Finally they will reach a temperature such that they are saturated with water vapour, that is, they are holding as much water vapour as they can. Now, if cooled further, this water will be deposited from the air upon a cold object in the form of dew. The temperature at which water will be deposited from the air upon a cold object is known as the *dew point.* The dew point is used as a measure of the humidity and apparatus is used for its determination.

SOME COMMON GASES

OXYGEN is a colourless, odourless, and tasteless gas. It will not burn but it supports combustion. Animals are dependent upon the oxygen in the air for life and will soon die if placed in an atmosphere without it. Pure oxygen may be breathed for a while without danger and it is used medicinally in cases where the breathing process is weakened. Oxygen forms about one-fifth of the atmosphere and, in combination, a large part of the rocks of the earth. It may be made in the laboratory by heating a mixture of potassium chlorate and manganese dioxide. Commercially it is generally made by liquefying air and then allowing the nitrogen, which has the lower boiling point, to boil off. The oxygen is stored in iron cylinders usually painted red. It is frequently used for oxy-acetylene torches for welding and cutting metals.

Oxygen will combine with several substances to form oxides. This combination is known as combustion. When objects burn they unite with oxygen. The rusting of metals is a similar process but it takes place much more slowly. The rust which is formed is an oxide of iron.

OZONE is another form of oxygen and, like it, is a colourless gas. It possesses a peculiar odour. It is more active than ordinary oxygen and will act as a poison to certain bacteria. It is sometimes used in cold storage to prevent the growth of moulds and to remove odours from the air. Ozone is prepared by passing dry air over an electric discharge. Its peculiar odour may often be noticed in the vicinity of apparatus where electrical discharges are taking place.

HYDROGEN is a colourless, odourless, and tasteless gas. It burns with a blue flame, and when mixed with air, is very explosive. It unites with oxygen to form water. It is the lightest gas known and on that account is used for balloons. Helium is now often used in the place of hydrogen being less dangerous, as it will not burn. Hydrogen may be manufactured by the action of mineral acids on some of the more common metals, such as iron and zinc, and is prepared on the commercial scale.

NITROGEN is a colourless, odourless, and tasteless gas, forming, as has been stated, about four-fifths of the atmosphere. It is a very inert gas as it will neither burn nor support combustion, and it combines with other substances with the greatest difficulty. In combination, nitrogen is of the greatest importance, being used for fertilizers, explosives, etc. Several processes are employed to bring the nitrogen of the air into combination so that it may be used commercially, and these nitrogen fixation plants played important parts during the recent war.

AMMONIA is a colourless gas with a very pungent odour. It is composed of nitrogen and hydrogen. It may be prepared by boiling ammonia compounds with lime, and it is sometimes the product of nitrogen fixation. It is very easily liquefed and is used extensively in refrigeration plants.

CARBON MONOXIDE: When carbon is burned with a limited amount of air some carbon monoxide is formed. This gas is colourless, odourless and tasteless, and is a deadly poison. Carbon monoxide will burn forming carbon dioxide and the blue flames seen in hard coal stoves and in certain gas heaters is due to the combustion of the carbon monoxide.

As carbon monoxide is so deadly too much care cannot be taken to avoid its presence. It is present in the exhaust from gasoline engines and several deaths have taken place owing to people allowing automobile engines to run while the garage doors are closed.

CARBON DIOXIDE: When coal burns with plenty of air carbon dioxide is formed. This gas is also colourless, odourless and tasteless, but differs from carbon monoxide in not being poisonous. It is present in waste gases from processes of combustion. Carbon dioxide is given off by animals when they exhale and it is absorbed by plants.

Carbon dioxide is easily liquefied and is sold in that form commercially in steel cylinders. It has an extensive use in soda fountains. It may be prepared in the laboratory by treating limestone with a mineral acid, and commercially it is often made by burning limestone in a kiln and compressing the gas which is

generated. When liquid carbon dioxide is allowed to escape suddenly from a small opening it will cool itself on account of its sudden expansion and form solid carbon dioxide. Solid carbon dioxide is a white solid resembling snow. Although it has a temperature of about $-80°$ C. or $-112°$ F. it may, if done carefully, be handled by the bare hands, as a protective envelope of gas is formed about the solid. Solid carbon dioxide is now being experimented with for use in refrigerator cars in place of ice. In some respects it is far superior to ice but it has a high cost.

Hydrogen Sulphide is a colourless gas with a very unpleasant odour similar to that of bad eggs. It is a compound of hydrogen and sulphur and is formed when proteins containing sulphur decompose. Hydrogen sulphide reacts with many metals to form sulphides, and the tarnish which so easily forms on silver spoons is a coating of silver sulphide. Cans used for lobster packing will often show a blackening due to the hydrogen sulphide within the can acting on the metal.

Sulphur Dioxide is the gas formed by the combustion of sulphur. It possesses the characteristic smell of "burning sulphur." It may be easily liquefied and is used extensively in domestic refrigerator systems. It dissolves in water to form sulphurous acid which has bleaching properties.

Chlorine is a heavy yellowish gas with a very sharp suffocating odour. It is used to a considerable extent commercially both as a gas and in the form of its compounds. Of the latter, sodium chloride, common salt, is probably the most important. Chlorine is prepared commercially by the electrolysis of solutions of sodium chloride. Chlorine may be obtained in steel cylinders, and in that form finds extensive use in the purification of water for drinking purposes. Chlorine came into prominence during the recent war as it was the first gas to be employed as a poison gas in the field.

Methane is a compound of carbon and hydrogen and is a colourless and odourless gas. It occurs in nature, apparently as the result of vegetable decay, and is often found in marshes and swamps; hence it is known as *Marsh gas*. It is also found in coal mines where it escapes into the workings. It forms an explosive mixture with the air and is known to the miners as *Fire damp*. It is the first member of an important series of compounds of carbon and hydrogen and has many useful derivatives. Methane is an important constituent of illuminating gases and occurs in natural gases. It is inflammable and burns with a blue flame.

Illuminating Gas: When soft coal is heated in a retort a gas is given off which is used for heating and lighting purposes.

The nature of the gas varies with the type of coal used in its preparation, but it generally consists of hydrogen, methane, carbon monoxide, nitrogen and some other gases. Before electricity was in general use for house lighting, coal gas was used for that purpose; but now its use is chiefly confined to domestic heating and cooking. In certain places gas occurs naturally and issues from the earth by means of a well. This gas is similar to coal gas but contains more methane. The residue left from the distillation of the coal is tar from which many dyes and other valuable products are obtained.

WATER

DISTRIBUTION OF WATER: Water is very widely distributed throughout the earth in its three states of aggregation, solid ice, liquid water, and water vapour. About three-fourths of the surface materials of the earth have been estimated to consist of water. Water occurs in combination in animals and plants as well as in some of the rocks. The following table will give some idea of the water present in some common substances.

	Per cent
Aquatic plants	95–99
Fish	80
Human body	70
Beef	60
Land plants	50–75
Clay	14

THE WATER CYCLE: Water in nature passes through a cycle. The heat of the sun causes evaporation of water from the sea. This water vapour is lighter than air and rises to the upper levels of the atmosphere where the lowered temperature causes it to condense to a mist forming clouds. These clouds form drops and the water returns to the earth in the form of rain, hail, snow, etc. The water runs through the earth, dissolving salts and wearing down rocks, and finally finds its way back to the sea by means of streams and rivers.

RAIN WATER: Rain water contains gases which it has dissolved in its passage through the atmosphere. It may carry some dust with it but contains a very small amount of solid material. It is thus very "soft."

SPRING WATER: Spring water is water which is travelling through the ground and draining from the surface. It will contain salts in solution, the nature of which will depend upon what sort of soil the water has passed through. If the water holds in solution some bodies which give it a particular taste or property it is known as *mineral water*. Water that contains salts of calcium and mag-

nesium in solution is known as *hard water*, and is made soft by adding substances which cause these salts to precipitate when they may be filtered off.

River Water: River water contains not only the substances which are in solution but also contains organic matter from plants growing on the sides and bottom of the river. On account of its greater volume and force a river will carry a considerable amount of suspended solids, as well as sewage and refuse from towns and villages situated along its banks.

Sea Water: As the rivers and streams flow into the sea all the solid materials carried by them, either in suspension or in solution, are deposited there. As the water evaporated is pure water, this solid material is gradually accumulated in the ocean. In places where the sea is land-locked and the temperature high, we would naturally expect to find the greatest amount of evaporation and hence the greatest amount of solids. On the average, sea water contains about 3·5 per cent of solids in solution. In the Baltic where there are numerous tributaries and less evaporation there is only about 0·5 per cent, while in the Dead Sea there is about 23 per cent.

Drinking Water: Not all water is fit for drinking as in its travel through the earth it may pick up all kinds of substances which are injurious to health. A water may be quite harmless although very muddy, as the mud may consist of harmless soil which may be easily filtered off. The water may contain bacteria of all kinds, some of which may be very harmful to mankind. Flowing water may improve in the course of its flow on account of the current and the presence of air. A river water may be polluted by sewage from a town, and yet in a few miles it may have improved so much that it may be safely used for drinking. Cities and towns often install large plants to filter and purify their drinking water. All water used for drinking purposes should be carefully inspected and its source known. A water high in chlorine should be very carefully examined. The chlorine itself is not dangerous but its presence usually denotes infection of some sort.

Water may be purified for household use by boiling, as this kills harmful bacteria. A further purification is to distill the water. Distilled water is absolutely free from all dissolved solids, although it may contain dissolved gases and liquids which may have distilled over with it. Distilled water is used in storage batteries as the water must be free from all metallic salts.

Ice: When water freezes it changes to ice, its solid form. When most bodies are cooled they become smaller but during the formation of ice we have an exception to this When water is

cooled its volume decreases, as we would expect, until it reaches a temperature of 4° C. As it is cooled further below that point it expands, so that consequently when a certain volume of water is frozen it will occupy a greater space than it did before. This is the reason why a bottle filled with water will sometimes burst if the water is allowed to freeze.

While liquid water when frozen forms ice, water vapour when frozen forms snow. Snow is a mass of tiny ice crystals, and the separate crystals may be readily seen.

STEAM: Steam is the vapour of water. It is a colourless gas but when issuing from a pipe into the air it soon condenses into a cloud of fine water drops which appear white. Steam occupies a much greater volume than water and one volume of water will produce about twelve hundred volumes of steam. The expansive properties of gases are well shown in the process of brogueing cans. The cans are heated in steam and water in the cans turns to steam. The cans are then pierced and the excess pressure within forces out the expanded air and steam. The hole is then sealed up, and on cooling, when the pressure is reduced there is a vacuum within the can. The steam inside the can drives out the air, and when the steam condenses to water the pressure is further lowered on the inside. This method removes the air from the contents of the can.

SOME COMMON LIQUIDS

AMMONIUM HYDROXIDE is the ordinary Aqua Ammonia of commerce which has well known household uses, being commonly used for cleaning. It is a solution of ammonia gas in water.

HYDROCHLORIC ACID, or Muriatic acid is a very strong acid. It is used in several industries. It may be prepared by treating common salt with sulphuric acid.

SULPHURIC ACID plays a most important part in industry, and it is said that the prosperity of a country may be judged by its consumption of sulphuric acid. The acid is a heavy oily liquid. It may be made by two processes on a large scale and may be shipped in tank cars. It is used in almost every branch of chemical industry.

NITRIC ACID is a very important chemical in the manufacture of dyes and explosives. Large quantities of it are used in every country. It is a strong corrosive liquid giving off brown fumes and turning the skin yellow.

GRAIN ALCOHOL or Ethyl Alcohol is a liquid obtained by the fermentation of sugar. It is used in various strengths in intoxi-

cating liquors. It has extensive uses in the manufacture of drugs and other chemical industries. Heavy duties are placed upon alcohol on account of its use in liquors, but it may be sold at much lower rates if it contains chemical substances which render it unfit for human consumption. Alcohol so treated is known as *Denatured Alcohol.* The substances added vary with the use for which the alcohol is required.

Wood Alcohol or Methyl Alcohol is not to be confused with grain or ethyl alcohol. It belongs to a large body of substances which are known as alcohols. It is a very deadly poison when taken into the human body, producing blindness and death. It is prepared by destructive distillation of wood, hence its name of wood alcohol. It is often used to denature ethyl alcohol and the resulting alcohol is known as methylated spirits. In recent years there have been many deaths from drinking wood alcohol and in the United States the chemical name of *methanol* has been adopted commercially to prevent confusion of wood alcohol and grain alcohol.

Formaldehyde is a gas but is always used as a solution in water. It belongs to a body of substances known as the aldehydes. It has a strong preservative action and is extensively used to kill bacteria and prevent decay.

Hydrogen Peroxide is another oxide of hydrogen. Hydrogen combines with oxygen to form water but under certain conditions hydrogen peroxide is formed. The liquid is very unstable and what is used on the market is only a weak solution in water. It very easily breaks up, turning to water and oxygen. The oxygen which is liberated makes it act as a germicide and cleansing agent.

Petroleum is an oily liquid which consists of various compounds of carbon and hydrogen. It occurs in the earth and wells are drilled to obtain it. The oil is in pockets many feet below the surface of the earth and the well is drilled down until the oil is found. Sometimes the oil will force its way to the surface and the well is known as a "gusher," but generally it has to be pumped to the surface. It is distilled in large stills and separated into fractions of different boiling points.

Gasoline is obtained from the first fractions of petroleum. It is a colourless liquid boiling at about 115° F. A mixture of gasoline with some of the fractions of lower boiling point is known as *petroleum ether*, while some of the fractions with a slightly higher boiling point than gasoline are known as naptha.

Kerosene oil is obtained from some of the higher fractions Its boiling point varies over quite a wide range.

Lubricating Oils are obtained from the higher fractions of the petroleum.

The residue or tar left after the distillation yields *vaseline* and other mixtures of the higher compounds of carbon and hydrogen.

THE ELEMENTS

Among all the substances known to man there are some ninety odd which have never been broken down into component parts. These substances are known as the elements and all other substances are built up from them by combination in various proportions and ways. Some of the more common elements will be mentioned and some of their properties described. Several of them have already been treated in the section on gases. A great many of the metals are elements and most of the elements discussed here are metals. Certain metals are made by combining two or more metals. The combined metal is known as an *alloy*. Alloys will be mentioned with the elements from which they are made.

Aluminium is a bluish white metal. It is lighter than most metals having a specific gravity of 2·6. It is unaffected in dry air, while in moist air a thin film of oxide forms and protects the metal from further corrosion. Most acids and strong alkalis attack the metal. Sea water rapidly corrodes it. Powdered aluminium has a strong affinity for oxygen and if ignited in the presence of iron oxide (or certain other metallic oxides) will set free the iron in the molten state. Powdered aluminium intimately mixed with iron is known as *Thermite*.

Copper is a reddish metal, and is one of the best conductors of heat and electricity. It is a very soft and may be beaten into foil and drawn out into wire. In moist air the metal becomes covered with a green carbonate called "verdigris." Copper is used to a great extent in alloys with other metals, gold and silver coins containing about 10 per cent of copper. Brass is copper and zinc. Bronze is copper and tin. German silver is copper, zinc, and nickel.

Iodine is a violet-black solid which has a metallic lustre. The iodine used for medical purposes is a solution of iodine in alcohol and is known as a *tincture* of iodine. Iodine is used in medicine as a tincture, and it is used for the preparation of certain drugs. It may be prepared from its compounds which occur in sea water and in the nitrate deposits of Chile. Iodine may also be obtained from a certain species of kelp. A certain amount of

iodine is necessary for the human system, and a deficiency is shown by a tendency towards goitre. In some localities table salt has iodine added to it in order to furnish iodine to growing children. Goitre is not so prevalent among people living by the sea coast as they can more easily be supplied with iodine.

IRON is a grey lustrous metal. It is attacked by acids. Dry air does not attack dry iron, but if a trace of moisture be present the iron becomes covered with a reddish brown film known as "rust." Iron rust is iron oxide and is similar to what is formed when iron is burned. Rusting is however, a much slower process than combustion. It is a very complex process and is not yet fully understood. Moisture is however necessary as dry iron in dry air will not rust. Steel is iron containing between 0·1 and 0·9 per cent carbon. Sheet iron dipped in molten tin forms "tin plate" which is used for making cans. The tin coating resists corrosion better than the iron, but if the tin be worn away at any point, the can will commence to rust at that point, and will in fact rust much quicker than if the tin had not been there. Iron coated with molten zinc is said to be galvanized and when thus treated will withstand corrosion, but as in the case of tin, if the zinc coating be broken, the iron below will be attacked very rapidly.

LEAD is a bluish grey metal, which is soft enough to be cut with a knife. Dry air and air-free water have no action on the metal but in moist air it becomes covered with a film of oxide. Water containing carbonates and sulphates in solution forms a protective covering on lead pipes. If water is pure enough to attack lead it is often filtered through limestone or chalk as sufficient lead might be dissolved to make the water poisonous.

SODIUM is a silvery metal which is very soft and may be easily cut with a knife. It reacts very readily with water forming sodium hydroxide and setting free hydrogen. If a piece of sodium be thrown on water it will rapidly dissolve with a hissing sound and the bubbles of hydrogen may be lighted with a match. The compounds of sodium are of great importance, but there are not many uses for the metal. It may be prepared by the electrolysis of molten sodium hydroxide.

TIN is a white lustrous metal which is soft enough to be cut with a knife but is harder than lead. Tin is only very slowly attacked by acids and alkalis and resists corrosion very well. This fact is taken advantage of in the manufacture of tin plate, which as mentioned, consists of plates of sheet iron dipped in molten tin. Tin is used in alloys, common solder being an alloy of tin and lead.

Zinc is a white brittle metal which is slowly oxidised in moist air. It is often used to protect iron by galvanizing.

SALTS

Salts are bodies resulting from the combination of an acid and an alkali known as a base. They are all crystalline bodies of various colours and are nearly all soluble in water. The base from which they may be prepared is a compound of a metal so that all salts really have two parts—a metal part and an acid part. Salts are often grouped as the salts of certain metals. The salts of sodium and potassium are of very great importance.

In the following section some of the properties of the more common salts are given.

Aluminium Potassium Sulphate or Potash Alum is one of a class of salts known as the alums. It is used medicinally.

Ammonium Chloride or Sal-ammoniac is a well known salt formerly used extensively in wet batteries.

Ammonium Nitrate and Ammonium Sulphate are very important as fertilizers.

Calcium Carbide is a compound of calcium and carbon used for generating acetylene.

Calcium Carbonate is common chalk. It occurs in nature and is extensively used in the preparation of quicklime.

Calcium Chloride is a white crystalline salt which is quite soluble in water. It occurs as an impurity in crude salt and as it has a great affinity for water it attracts it causing the salt to cake. It is used to obtain low temperatures as has been stated.

Calcium Oxide is quicklime which is produced by burning calcium carbonate, common chalk, in a kiln. Quicklime reacts with water very easily giving off heat and forming calcium hydroxide, or slaked lime.

Calcium Sulphate is gypsum. It contains water and when this is driven off by heating in a kiln Plaster of Paris is produced. Calcium sulphate occurs in hard water.

Copper Sulphate is the familiar Blue Vitriol or blue-stone. All copper salts are poisonous and cannot be used in food products.

Lead Acetate, sugar of lead, is a very poisonous lead salt. All lead salts are poisonous and care should be taken to keep them from getting into food. Lead pipes should not be used for water

if that particular water shows signs of dissolving the lead. Tin containing lead should not be used in the manufacture of tin cans as acetic or organic acids which might be in food stuffs will dissolve the lead.

MAGNESIUM SULPHATE, or Epsom salts, is a white salt which is very soluble in water. It occurs in the sea and is often found with common salt as an impurity. Magnesium salts occur in hard water.

MERCURIC CHLORIDE or Bichloride of Mercury is a white salt which is a violent poison. It is often used medicinally and in antiseptic solutions. The greatest care should be taken in its use. All mercuric salts are extremely poisonous. Mercury compounds are used in some marine paints.

MERCUROUS CHLORIDE, or calomel, is not to be confused with the other chloride of mercury, mercuric chloride. While the latter is a deadly poison, calomel is often used medicinally. Great care should be taken not to confuse these two salts.

Potassium salts are very like the corresponding salts of sodium. They occur mostly on land but some of them are found in the ashes of certain species of kelp, which are used on the Pacific coast as a source of potash. Clay has the property of retaining potassium salts to a greater degree than sodium salts. Thus as rain water seeps through the soil, the potassium salts are retained while the sodium salts are carried on to the ocean. Potassium salts are greatly used as fertilizers and the main bulk of the supply comes from large deposits found in Germany and France.

POTASSIUM NITRATE or Saltpeter is used in gun powder and in preserving meat.

SODIUM BICARBONATE, or bicarbonate of soda, is used in cooking as baking soda. It is also used medicinally.

SODIUM CARBONATE or washing soda is used extensively in industrial work as an alkali. It is used to soften water as it will precipitate the calcium and magnesium as insoluble carbonates.

SODIUM HYDROXIDE or Caustic Soda is used as a strong alkali. It makes a very caustic solution.

SODIUM CHLORIDE is the chemical name for common salt. It has a very extensive use for industrial purposes and for human consumption. There are two sources of salt. Sea salt, which is obtained by the evaporation of sea water: and rock salt, which is mined from deposits found under the earth. As sea salt is the residue left when sea water is evaporated it will contain all of the solid material that was in the sea water.

According to the chemist sodium chloride should consist of sodium chloride and nothing else. Anything else that may be present is called an impurity no matter what it might be. The most common impurities are salts of calcium and magnesium. These play a great part in the salting of fish as they alter the appearance and flavour. Some typical salt analyses are here given.

Kind of Salt	Turk's Island	Spanish	California	Malagash
Sodium chloride	96·52	98·05	99·96	99·09
Calcium chloride	....	0·49	....	0·12
Calcium sulphate	1·53	....	0·06	0·40
Magnesium chloride	1·20	....	....	0·03
Magnesium sulphate	0·80	0·80	0·01	....
Sand, etc	0·13	0·06	0·02	0·35

Table salt is refined so as to be free from those impurities as calcium chloride and magnesium chloride which absorb water and make the salt stick. Some table salts have magnesium carbonate added to make the salt run freely.

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